Modeling Elementary Cognitive Abilities for Adaptive Hypermedia Presentation

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Abstract. The adaptation of hypermedia can be carried out at three levels, namely the content, navigation and presentation level. The presentation level is the least studied of the three, apparently because it refers to user properties that are not easy to model. In this paper, we present a new approach to modeling cognitive abilities that relies on basic mental functionalities. We describe the CUMAPH environment (Cognitive User Modeling for Adaptive Presentation of Hyper-Documents), which mainly provides an authoring tool and an adaptation engine. The aim of this environment is to adapt a hyper-document presentation by selecting the elements that best fit the user cognitive profile. Its architecture is based on four main components: a cognitive user model, a hyper-document builder, an adaptation engine and a generic style sheet. To validate our approach, we designed an innovative protocol and conducted an experimental study involving 39 students. The first results show that an adaptive presentation can significantly increase the efficiency of hypermedia presentations.

Key words: Cognitive indicator, adaptive hypermedia, document model, empirical evaluation.

1. Introduction

In his review of adaptive interfaces and agents, Anthony Jameson (2003) suggested that the different functions of adaptive systems would fall into two categories: supporting system use (taking over parts of routine tasks, adapting the interface, giving advice about system use and controlling a dialogue) and supporting information acquisition (helping users to find information, tailoring information presentation, recommending products, supporting collaboration and supporting learning) (Rossi et al., 2001) (Stephanidis et al., 1998). Hypermedia systems are strongly affected by these functions. For instance, one of the main goals of Adaptive Hypermedia (AH) systems is to decrease the cognitive load caused by pieces of information that are irrelevant to the goals and/or the abilities of users. Brusilovsky (1996) defined a first taxonomy of techniques and methods that are used in AH systems. This classification distinguished two types of adaptation. Navigation adaptation provides navigational support to hyper-document users by emphasizing and restructuring links, while adaptive presentation adapts the content of the pages to users' goals, abilities, knowledge, language, etc. In presentation adaptation, most research is focused on content selection or, on the display side, on the adaptation of content to the device (PC, PDA, mobile phone, TV set, etc.). This is supposed to manage layout and/or select interaction techniques. Little research exists that tries to help users to focus their attention on "presumably interesting" items using graphical artifacts such as zooming techniques (Tsandilas & Schraefel, 2003).

Because human cognitive abilities are key factors in the efficiency and usability of Human-Computer Interaction, and because massive progress have been done by cognitive sciences in the last decade, we think that it is possible to better use cognitive modeling for adaptive presentation of hypermedia. We are interested in providing technologies that allow having fine grain adaptation (i.e. inside the documents) without requiring strong expertise or heavy work for the author of the hypermedia.

After a brief review of current applications of cognitive psychology in user modeling, mainly discussing cognitive styles and cognitive architecture, we present an environment called CUMAPH for "Cognitive User Modeling for Adaptive Presentation of Hyper-Documents". This environment is based on four components: a cognitive user model, a hyper-document generator, an adaptive engine and a generic style sheet to present the adapted hyper-documents. We view the presentation adaptation as a process of selection of the most suitable combination of interactive elements. By combination, we mean an item or a collection of multimedia items (text, images, audio and video) that describe a concept or provide an explanation. The best combination is the one that most fits the user cognitive abilities. In order to model these abilities, we have defined a cognitive profile, which is a set of valued indicators representing elementary cognitive functions. Techniques dealing with the construction of the user profile are drawn from work in cognitive psychology and human computer interface. This multidisciplinary approach is a key contribution for future works in the field.

In the last part of this paper, we present and discuss the results of an empirical study to validate our approach. We built an innovative protocol using randomized profiles. We are convinced that this protocol can be reused in other contexts where it is difficult to build counter-balanced situations, which is mostly the case in adaptive context. The results of this experiment indicate that our approach is promising and they give valuable feedback about future work.

2. Cognitive Modeling

Attempting to enhance the usability of Human-Computer Interaction, and especially the interaction with hypermedia, often raises the need for understanding the correspondence between the software interface and the user mental functionalities. However, modeling cognitive behaviors is a difficult task that requires expertise in cognitive psychology and neuropsychology. In addition, defining cognitive profile will obviously simplify and reduce the complexity of real human behaviors. The question becomes "Are these simplified models good enough for practical use?" As a consequence, the purpose of this research field is to find models that best represent the reality and that can be usable. Before presenting our proposal, we briefly introduce two very different ways to handle such problems: cognitive styles and cognitive architectures.

2.1. COGNITIVE STYLES

Cognitive styles refer to a person's habitual, prevalent, or preferred mode of perceiving, memorizing, learning, judging, decision-making and problem solving. Individual differences about how people carry out tasks involving these functions may build up a style if they appear to be (1) pervasive, which means that they emerge consistently in different contexts, independently of the particular features of situations; or (2) stable, which indicates that they remain unchanged at different times. Cognitive styles are supposed to be one of the most stable user characteristics overtime (Dufresne, 1997). They are consistent through a variety of situations, as opposed to the user's knowledge or experience that are more specific and evolving. Many researches have shown the importance of cognitive styles in the area of HCI and their implication in the interface design (Muylwijk et al., 1983).

Cognitive styles lead people to adopt similar attitudes and behaviors in a variety of domains (Daniels, 1996). They are important in determining the most effective interface for a particular category of user, especially in the formative stages of interaction (Fowler et al., 1985).

They can be conceptualized as a cross-road of thoughts, personality, and motivation. In fact they contain the strategies that someone tends to apply when they face a situation, and the users' preferred way of processing information. They are strongly linked to "learning styles" (Smith & Kolb, 1984) (Felder, 1996).

Defining cognitive styles is a complex task. Some proposed researches suffer from a lack of scientific validation while others are not readily usable in interactive systems especially in e-learning environment (Habieb-Mammar, F. Tarpin-Bernard, 2002). Some of the most referenced cognitive styles are "field-dependent/independent", "impulsive/ reflective", "analytic/descriptive", "conceptual/inferential", "thematic/relational", "analytic/global" (see Liu & Ginther, 1999, for a more detailed review).

Assessment of Cognitive Styles

Three main kinds of data can be used to measure cognitive styles: behavioral, self-report, and physiological (Antonietti & Giorgetti, 1998).

Behavioral data can be obtained by recording the final result of a given task or the procedure applied when performing the task (Lohman & Bosma, 2002). Most of the time, the task consists of filling out a paper-and-pencil test, a multiple choice test or a sorting test.

Self-reports require that people evaluate themselves by describing introspectively the way they performed tasks by checking personal habits or preferences, or by endorsing statements about what they think of themselves. This may be done, for example, by asking subjects to keep a diary of what happened during a specific period of their life; by interviewing them, or giving them questionnaires to fill.

Finally, some *physiological measures* can be interpreted as hints of particular cognitive preferences in processing stimuli (Monaghan & Shillcock, 2004). Indeed, observations of physiological measures have indicated that when someone is asked a question that requires some thinking, eyes make an initial movement to the left or right. Since it was argued that the right cerebral hemisphere is associated with the processing of visual information and that spontaneous lateral eye movements are under the control of counter-lateral hemisphere, it was claimed that the presentation of a visual-spatial question produces the activation of the right hemisphere, and consequently left lateral eye movements (Kelly et al., 2004). Thus, it has been suggested to use lateral eye movements as a criterion to assess the preference for either a visual or a verbal processing.

Limits of Cognitive Styles

"Cognitive styles" is a disputable concept that is not fully accepted by the whole community. Similarly, Coffield et al. (2004) have recently tried to scientifically validate the main learning styles and showed that many of the tests used to identify such styles suffer from the lack of reliability. In addition, as commonly happens when we try to classify a large group of people, a number of them would not fully belong to a specific class. For instance, when someone fills a cognitive style detection test, it is common to obtain mixed result for the same person (e.g. 60% style A – 40% style B). In these situations, it is difficult to attribute a stereotyped profile to those users.

Even when they are well defined and easily identifiable, cognitive styles and learning styles are not easy to use in adaptive technologies. Most of the time, they are used for the selection of a customized presentation. Indeed, a course designer in an e-learning environment may prepare several independent versions (micromodules) corresponding to the different styles and the system selects one according to the user style (see 3DE project for instance, www.3deproject.com or Danchak, 2004). The Micromodule is a learning unit composed of text, images, interactive animations and multimedia content (Del Corso et al., 2002). It is an autonomous unit that can be used alone to teach an elementary concept (however the micromodule is generally conceived and designed for delivery in a context). Thus, these kind of macro-styles often involve deep changes in the hypermedia (content, structure and examples). Such work can be very profitable to learners but obviously very expensive and difficult to apply in an extensive manner. In addition, it requires a high competency of authors. As a conclusion, cognitive styles can be effectively applied in adaptable interfaces but not so easily used in adaptive hypermedia.

2.2. COGNITIVE ARCHITECTURE

Young et al. define a cognitive architecture to be an embodiment of "a scientific hypothesis about those aspects of human cognition that are relatively constant over time and relatively independent of task" (Gray et al., 1997; Ritter & Young, 2001). Cognitive architectures are designed to simulate human intelligence in a humanlike way (Newell, 1990) and try to fulfill one of the visions held by many in the cognitive architecture community: a high-fidelity "virtual user" that could potentially use any application. In our context, these works are interesting because they try to model cognitive structures.

There are currently several cognitive architectures that are being actively developed, updated, and applied to HCI-oriented tasks. Most of them are production systems, which are systems based on rules like "IF THEN" condition-action pairs, or rather are centrally built around production systems. The most famous are Soar (Newell, 1990; Altmann & John, 1999), EPIC (Kieras & Meyer, 1997), and ACT-R/PM (Byrne & Anderson, 1998; Byrne, 2001).

Providing accurate quantitative models for Graphical User Interface (GUI) applications requires a system with detailed models of human perceptual and motor capabilities. Constructing a model in EPIC thus requires specification of both the knowledge needed in the form of production rules as well as some relevant perceptual-motor parameters. There are two types of parameters in EPIC: standard, which are system parameters believed to be fixed across all tasks, and typical, which are free to vary across task situations, but generally have conventional values. A standard parameter in EPIC is the duration of a production cycle in the Cognitive Processor, which takes 50 ms (milliseconds. An example of a typical value is the time needed by the Visual Processor to recognize that a particular shape represents a right arrow, which is 250 ms.

ACT-R/PM (Byrne & Anderson, 1998 ; Byrne, 2001) represents another approach to a fully unified cognitive architecture, combining a very broad model of cognition with rich perceptual-motor capabilities. ACT-R/PM is an extension of the ACT-R cognitive architecture (Anderson, 1993; Anderson & Lebiere, 1998) with a set of perceptual-motor modules like those found in EPIC.
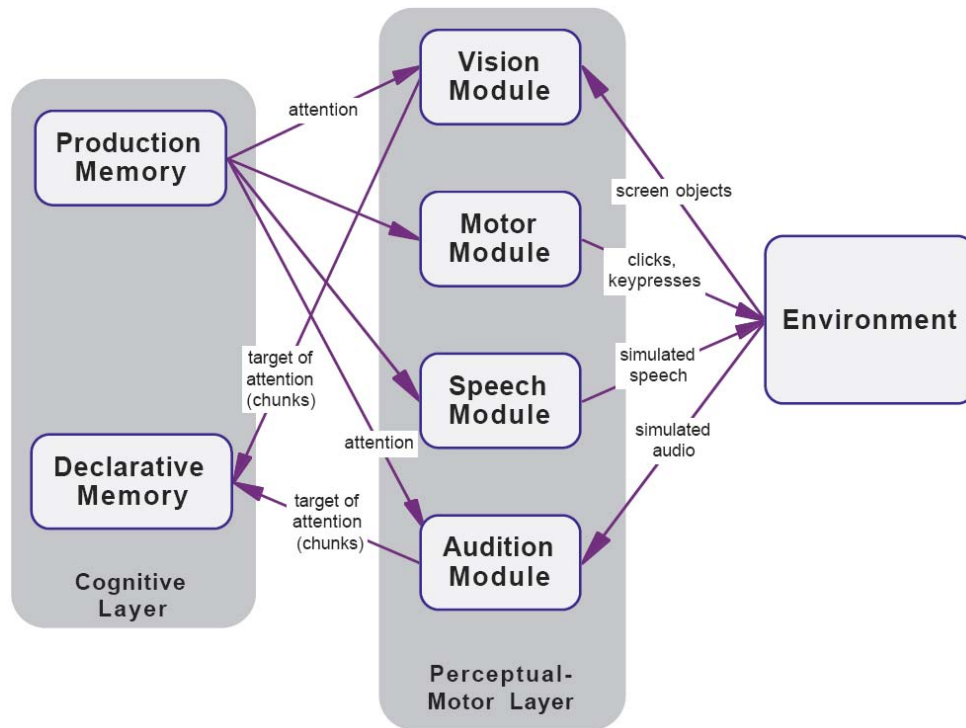

Figure 1: Overall structure of the ACT-R/PM architecture. Based on Byrne and Anderson (1998).

One problem that will never be entirely resolved, no matter how diligent the modelers are, is the knowledge engineering problem. Every model constructed using a cognitive architecture still needs knowledge about how to use the interface and what the tasks are. This requirement will persist even if an architecture were to contain a perfect theory of human learning, and there is still considerable work to be done to meet that goal.

Another barrier to the widespread use of cognitive architectures in HCI is that the architectures themselves are large and complex pieces of software. Irinically, little work has been done to make them usable or approachable for novices (Byrne, 2003).

2.3. COGNITIVE ABILITIES

Definition

Cognitive abilities are mechanisms that allow humans to acquire and recognize pieces of information, to convert them into representations then into knowledge, and finally to use them for the generation of simple to complex behaviors (Lemaire, 1999). Some cognitive abilities are highly coupled to perceptual abilities because they are sensitive to acquisition modalities (view, hearing, touch, taste, smell). Cognitive psychology describes the mental functionality in

terms of interactive and independent systems or modules (see cognitive architecture in the previous section). The real architecture of a cognitive system is not yet known. Nevertheless, it is possible to distinguish a set of sectors depending on: the type of information, its presentation and the behaviors triggered. Cognitive abilities vary from one person to another. They are mostly and progressively influenced by age. Some of them are very stable in a long-term range whereas others can vary according to stress, tiredness or drug effects.

Cognitive abilities are commonly classified under five sectors: memory, attention, executive functions, language and visual and spatial abilities.

Memory is the set of mechanisms responsible for acquiring, storing and finally re-using information. It is not a unitary function; it is divided into different sub-systems according to:

- The learning or reminder nature (conscious or unconscious),

- The type of strategy employed (verbal, visual…),

- The quality of memory stored (personal experience, cultural facts, specialized memory and motor procedures).

Attention is fundamental in intellectual efficiency. It is essential in the majority of cognitive tasks. In some cases, the mobilization of attentional resources allows either the favor of a stimulus among others (focalization), or the parallel treatment of several surrounding areas of stimuli (distribution). Working memory is a specialized form of attention, which temporarily stores information during the execution of a complex cognitive activity.

Language brings together the set of expression processes and understanding according to two codes: oral and written. It constitutes the most important communication means of an individual who has modules monitoring sounds, spelling, word meaning, grammatical progression, comprehension procedures and speech organization.

Executive functions correspond to more elaborated functions such as:

- logic and strategy,

- planning, forecasting and adaptation,

- problem-solving and hypothetical-deductive reasoning.

The **visual and spatial** field (also called visuospatial) deals with pattern recognition and systems identification as well as with shape positions analysis. It allows mental manipulations of shapes like spatial rotations. In this case, we talk about mental imagery.

Cognitive Indicators

In collaboration with the SBT Company, we have been working since 2000 on HAPPYneuron™, an interactive website of supervised cognitive training: www.happyneuron.com (Tarpin-Bernard et al., 2001). Mainly dedicated to seniors, this website provides 50 exercises that train and evaluate cognitive abilities. In order to precisely qualify which cognitive functions are involved in each exercise, we divided each cognitive sector in elementary abilities called

cognitive indicators. Thus, the memory sector is split into 4 sub-elements: cultural memory (e.g. things learned at school), episodic memory (events or episodes experienced personally), recent declarative memory (long-term memory that stores recent information) and procedural memory (trained sequences). The attention sector is subdivided into 3 main elements: working memory (structures and processes used for temporarily storing and manipulating information), short-term memory (which stores information for less than 1 minute and whose capacity is very small, holding 7 ± 2 items (Miller, 1956)) and selective attention (the ability to process information from only one part of the environment with the exclusion of other parts). As cognitive architectures clearly showed, acquisition and storage are strongly related to perceptual abilities. As a consequence, we divided recent memory, working memory and short-term memory into 9 elementary indicators (3x3) to distinguish the modality of the information: visual (images), verbal (text) and auditory (music). The language sector is divided into 4 indicators: lexical spelling (richness of vocabulary), categorization (classification skill), understanding (text comprehension), and arithmetic (mathematics language). This classification has been done for training purposes as explained earlier. It is obvious that a more precise subdivision could be done if someone wants to more deeply segment this sector. The executive functions sector is divided into 4 indicators: planning, strategy, reasoning (hypothetical-deductive reasoning) and interference sensitiveness (ability to resist to interference or ability to manage double tasks). The visuospatial sector contains 3 indicators: mental imagery, form recognition and visual exploration. Finally, HAPPYneuron uses 25 cognitive indicators to define a cognitive profile.

In practice, an exercise never involves a single indicator. Each cognitive activity results from a parallel or hierarchical processing of several cognitive abilities. As a consequence, for each exercise, the psychologists who designed the tasks have determined the indicators involved and chosen weight factors ($0 \leq w_i \leq 10$, $\sum w_i = 10$) for each of them.

During each training session (i.e. each connection), the user performs a set of exercises suggested by the system. Exercises have a playful dimension and vary in difficulty level and speed in order to entertain and train the user. Normalized data (percentile distribution of scores) are stored into a database for each variant of exercise and family of population distinguishing gender, educational level and age. Current statistics show that since the web site was opened to the general audience (summer 2001), the number of performed exercises has exceeded 4,000,000 and the population of players is well distributed between 15 and 80 years of age. Comparing users' results and normalized data, we are able to progressively build their cognitive profile.

Relying on this unique experience, we are now able to build evaluation modules composed of *n* exercises that allow to quickly build a cognitive sub-profile that describes a subset of cognitive indicators. Depending on the size of this subset, n ranges between 4 and 8. For each exercise, the user performance (exactness and speed) is converted into a score S ranging from 0 to 100 using percentile tables that compile and linearize the thousands of performances already done (between 10.000 and 200.000 according to the exercise). That way, a score of 90 will be given for a performance

higher than the performances done by 90% of the population. On the opposite, a score of 20 will be given if only 20 % of people obtain lower performances. As time response is better when it is smaller, the final score for speed is 100-S. In the example presented in Figure 2, a time response of 500 ms will give a mark of 35 (100-65).
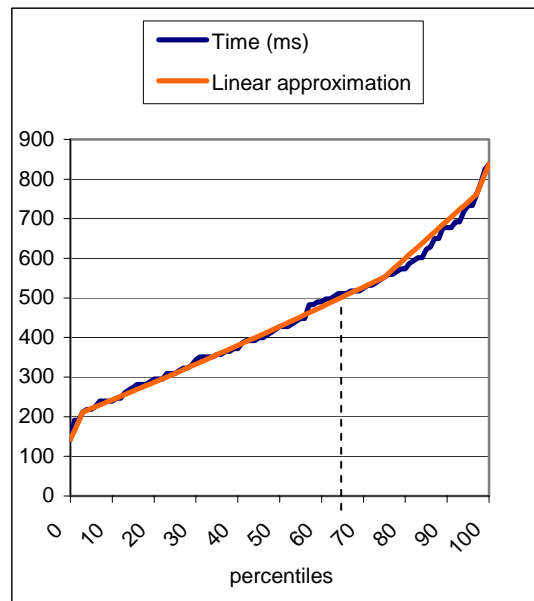

Figure 2: Example of normalization of raw performances using percentiles.

As each exercise involves several indicators, these indicators are modified by the final mark according to the weights w_i. At the end of the evaluation module, each cognitive indicator is valued. 50 correspond to the average level. In the case of a Gaussian distribution of the performance, 3 and 97 respectively correspond to M-2σ and M+2σ where σ is the standard deviation and M the mean. Because exercises are specially designed to have a good reliability, and thanks to our scoring technique, test-retest reliability coefficients vary between .80 and .95 depending on the exercises.

A cognitive profile is usually very stable (except in case of high stress or drug consumption) and can be defined once and used in various contexts. This is very interesting because contrary to cognitive styles, cognitive indicators are not highly dependent to tasks. For instance, if we consider two comparable tasks (exercises) that mainly required visual short term memory, we observe similar levels of performances.

The Use of Cognitive Indicators in Adaptation

Because cognitive indicators have some interesting properties, mainly task independence and stability, and because they have direct relationships with perceptual abilities, we think that they can usefully serve as parameters for dynamic adaptation of hypermedia presentations. Our hypothesis is that not all indicators can be used but conjunctions of some of them can help to describe the user's skills for information processing and thus can be used to adapt presentation.

The principle of our adaptation process consists of dynamically building web pages selecting multimedia elements that fit to the user cognitive profile. The choice is done among a set of equivalent elements prepared by the author and is

based on the maximization of a set of criteria that mainly involve cognitive indicators and characteristics of elements. Our assumption is that if a multimedia document fits well with the user cognitive abilities, then it will increase the memorization capacity of the user and reduce his/her cognitive load.

Our first goal is to use the cognitive indicators for adaptive presentation of hypermedia in e-learning contexts. Depending on the user's profile, the course will be presented using the most adapted media. This requires defining adaptation mechanisms and hypermedia builder tools. One of our main concerns is to build and validate technologies that can be easily used by authors. Our proposal is called CUMAPH.
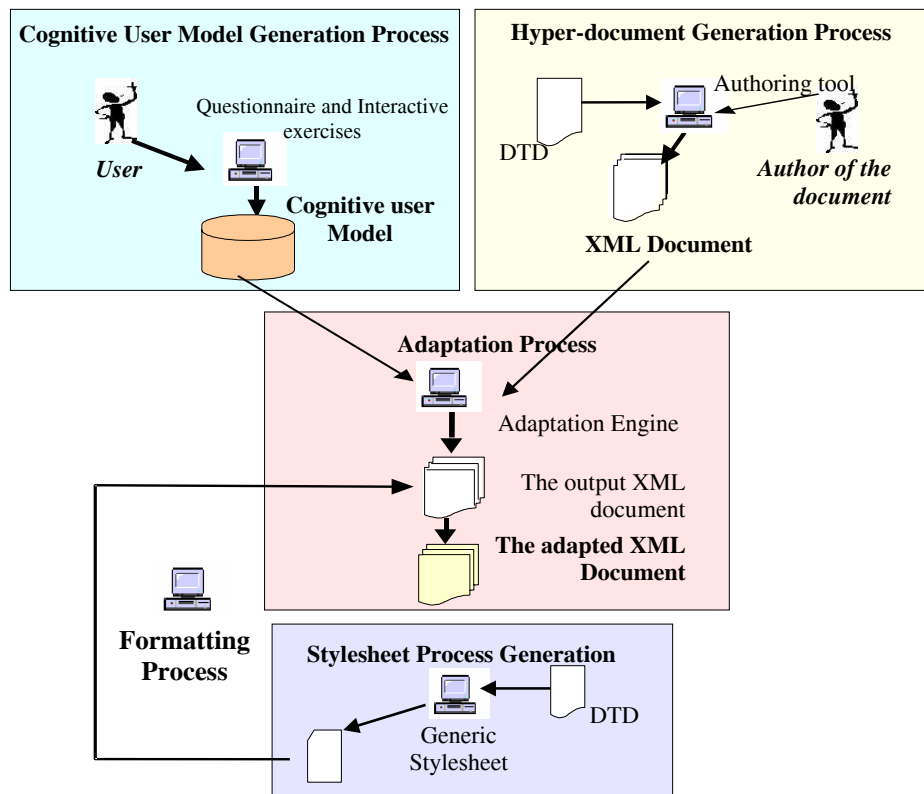

Figure 3: The four processes of CUMAPH

3. Description of the CUMAPH Environment

CUMAPH is an environment in which the hyper-document presentation is adapted according to the cognitive user model. It is composed of four components (Figure 3):

- The "Cognitive User Model Generator" is used to build the user cognitive model using interactive exercises.

- The "Hyper-document Generator" is used by the author of the hyper-document to build XML pieces of documents.

- The "Style sheet generator" consists in building a generic style sheet for sets of hypermedia.

- The "Adaptation engine" builds an adapted version (structure) of an XML document and applies the style sheet.

The first three ones are used before the adaptation, whereas the last one is in charge of the dynamic adaptation.

In the next sections we detail these four processes.

3.1. GENERATION PROCESS OF A COGNITIVE USER MODEL

Relying on the unique experience of HAPPYneuron™, we built an evaluation module composed of 7 exercises that enables a user to quickly construct his/her cognitive profile. This simplified profile includes four sectors (memory, attention, language and visuospatial) and is focused on differences between modalities (verbal, visual or musical). It involves 13 cognitive indicators: verbal/visual/musical working memory, visual/verbal short term memory, visual/verbal/musical long term memory, form recognition, categorization, understanding, glossary and spatial exploration. This module could be usefully extended, but it already requires 30 to 35 minutes to be achieved. A second test could also extend the first one. This is one of the strengths of the approach because it is very easy to add exercises without implying a heavy validation process. Each exercise (in French) is highly interactive and requires the user to achieve complex tasks (Figure 4 shows the equivalent exercises in English):

- In "Around the World in 80 Trips" the user has to memorize itineraries and locations

- "Split Words" measures lexical fluency and space analysis

- "This Story is full of Blanks" requires a high level of mastering the language (structure, grammar, meaning)

- "Entangled figures" implies form recognition and requires visual attention

- "Funny Grammar" involves language classification

- "Waiter, please" involves memorization of dinner menus with spatial cues

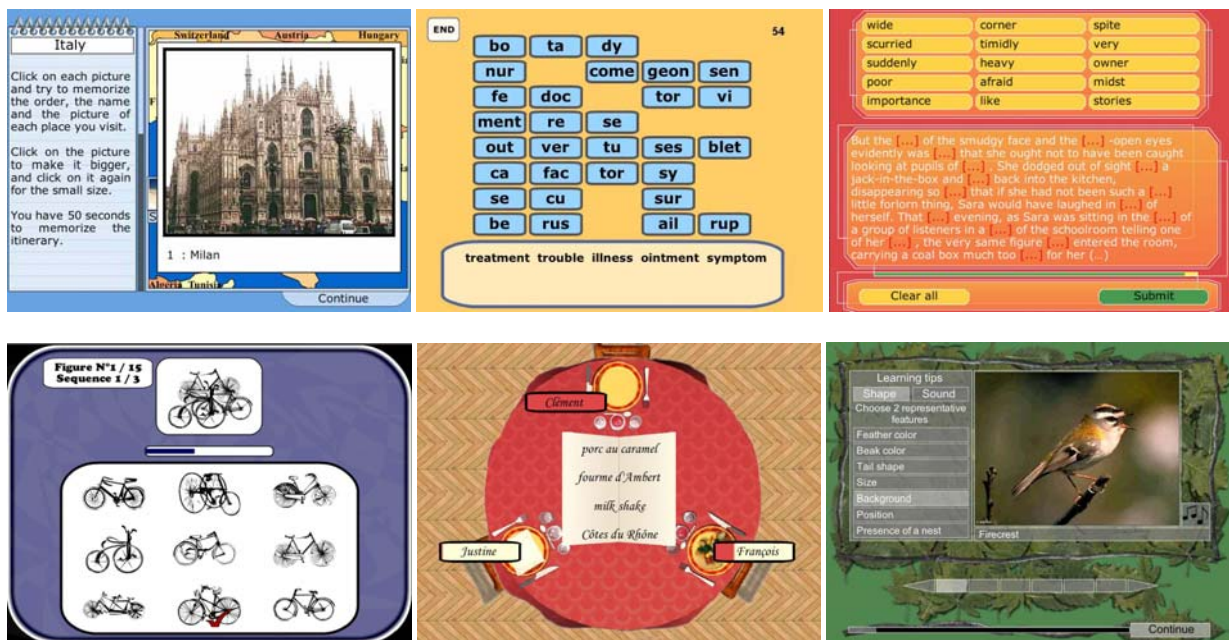- "Bird Songs" requires audio/musical memory

Figure 4: Some interactive exercises extracted from an interactive cognitive evaluation module.

The Hyper-document Model

We use a classic model where the hyper-document is made of XML pages. Each page comprises blocks that correspond to various concepts (e.g. title, definition, example, concept #2 or menu). Usually, each block can be presented using different elements that use the same semantics (e.g. a diagram vs. its textual description). Due to the particular properties of each type of media, some elements in a block can contain more details than others but the key concepts have to be present in each of them. An element is associated with media types and can be mono or multimedia (e.g. a figure and its caption, a video and its textual comment). Video, images and sounds are external media.

In order to model hierarchical hyper-documents as well as more graph-oriented hypermedia, blocks can be externalized (stored in separate files) to allow several pages to refer to them (Figure 5).
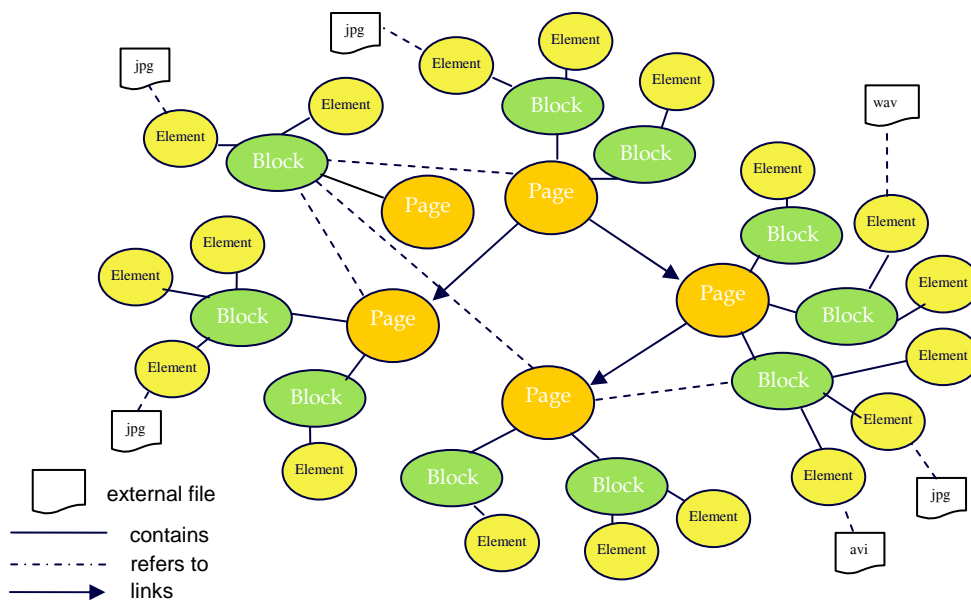

Figure 5: Main structure of the hypermedia.

Each page of the hypermedia follows an XML DTD (Data Type Description). To make it more legible we provide a simplified representation of this structure in Figure 6.

```
Page [title, style]
      block [name, group, position, include]
              element [name, signature, state]
              content [type="text" : "sound" [duration, autostart] : "image" [width, height, link] : "video"
              [duration, autostart, width, height, link]]
      rules
              combi
      exclude
              combi
      links
              link [key_word, url, position]
```

Figure 6: XML structure of each page (tag [attributes])

This XML description language models our hierarchical structure and adds several important entities.

First, the block tag has 4 attributes:

- "*name*": useful for the author in the generation tool we will describe later;

- "*group*": optional textual reference that links several blocks. This feature constraints the adaptation engine so that all the blocks of a given group are processed identically. A simple example of the use of this property is when we have three navigation blocks (previous, next, main) that have several presentations (graphical button, textual link, etc.). Using the same "group" reference insures that the same presentation will be selected for each block. This is a basic way to ensure coherence and homogeneity of presentation.

- "*position*": this attribute is used later by the style sheet for the layout. This feature can be more sophisticated. Currently, we use a technique similar to Java layout defining 5 positions (center, left, right, top, bottom). Some areas can be empty; in which case the central area is automatically extended to fill them. Usually, the center area is used by main data while the others are dedicated to navigation purposes. When several blocks use the same area, they are presented consecutively using their order of appearance in the document.

- "*include*": this optional attribute is used if the block is external (i.e. defined in another file). This string gives the path name of another XML file, which is a page that contains the referenced block.

Our main goal is to study the effect of the presentation adaptation; therefore we did not feel the need to include items that model semantics in the structure. However, they may need to be added to obtain a fully usable model.

As mentioned earlier, the goal of our adaptation process is to select the elements that will maximize a set of criteria based on cognitive indicators and some characteristics of elements. We store these characteristics in an attribute called *signature*. Because perception and cognition are highly coupled, this signature describes 4 dimensions and is a hybrid model that mixes perceptual and cognitive characteristics:

- the Visual component (V) describes the complexity of visual information contained in the element (mainly in videos or images) ;

- the Audio/Musical component (M) is related to the complexity of audio information contained in the element (mainly in videos or sounds) ;

- the Kinesthetic component (K) describes the interactivity of the element and the realness of the materials (abstract vs. concrete) ;

- the Language component (L) qualifies the complexity of verbal information contained in the element (in texts, diagrams, videos, sounds).

Each dimension of the *signature* is a representation of the "level of complexity" and ranges from 0 to 5. Complex and composed elements have rich signatures. For instance, a diagram and its caption could have a "L3V2M0K0" signature,

whereas a 10 seconds video could have a "L3V5M3K2" signature. To help the author in the assignment of signatures, we have established a guideline table (see Table 1).

Table 1 Examples of cognitive signatures

Signature component	L	V	M	K
1	caption, title, key words…	Icon, button… Long text (requires visual exploration)	Beep, background music without meaning	Clickable element
2	2 lines sentence, diagrams with text, short voice	Simple diagram	Jingle or recognizable sound (2-3 seconds)	Simple animation
3	5 lines paragraph, medium voice	Diagram, simple drawing	Short sound (3-10 seconds)	Animation with menus
4	10-15 lines paragraph, long voice	Complex diagram, medium size picture	Long sound (10-30 seconds)	Animation with direct manipulation
5	Full page, full interview	Rich picture	Very long sound (more than 30 seconds)	Complex interactive anima-tion
comment	The value can be in-creased if the structure or if the vocabulary is complex	The value can be increased if the media has many details	The value can be increased if the sound is live and difficult to hear	The value can be increased if the media refers to real world (concrete examples)

Each element contains one or more media (*content*): text, image, sound or video. Depending on the media type, several attributes are automatically assigned by the generation tool like *width*, *height* or *duration*. Two other attributes can be specified by the author: *autostart* (Boolean) if she wants an auto-start of the media (sound or video) and *link* (string) which is a hyperlink reference.

These hyperlinks are actually defined in the final **links** section. A line describes each link specifying the key words (to find in the text or in the *link* references of images or videos) and the URL (a virtual reference to another XML page or a classical Web URL if it is external to the current site). The third attribute (*position*) is an optional list of numbers that specify occurrences of the keywords in the text in case of numerous occurrences (e.g. if we define a link on the "memory" word which has 10 occurrences, we can declare to have links on the "memory page" only for occurrences #1 and # 4). This technique has been chosen to externalize hyperlinks so that they can be mapped on the different media.

As we will show in section 3.3, the adaptation engine will analyze all the possible combinations of elements described in a page in order to estimate which one is the most compatible with the user profile. This is an automatic process but, if necessary, the author can limit the possible combinations to be analyzed. There are two ways to proceed. First, the authors can list, in the *rules* section, the combinations they want the engine to consider. The second way consists of listing, in the *exclude* section, the combinations they want the engine not to consider. Each *combi* tag in the XML file describes a combination (e.g. L1V0M0K0$L0V1M0K0) using the $ character as a delimiter between the signature of its components. These strings are generated by the authoring tool that we present in the next section. That way, if the authors have 3 elements with the following signatures: L5V0M0K0 (text), L4V0M4K0 (recorded voice), L1V4M0K1 (diagram), they can force the system to choose between two bimodal combinations: (L5V0M0K0+L1V4M0K1) or (L4V0M4K0+L1V4M0K1).

```xml
                                                                        Attention_saga4.xml
    <Page>
     <bloc name="part 1" position="center">
        <title>L'ATTENTION </title>
        <element name="E1" signature="L3V1M0K0">
            <content type="text"><b>L'attention peut être sélective :</b><p/>Etant donné qu'il nous est impossible de traiter
simultanément toute l'information qui se présente à nous, une analyse successive des informations est réalisée. <p/>Entre en
scène l'attention dite sélective.<p/> Ce type d'attention opère dès lors que nous avons un choix à effectuer pour la sélection
d'une information répondant à nos attentes dans des circonstances données.</content>
        </element>
        <element name="E2" signature="L1V3M0K0">
            <content type="text"><i>Si l'on est à la recherche de champignons, l'attention sélective se focalise sur le sol, les
autres informations de la scène étant ignorées.</i></content>
            <content type="image" width="270" high="300"> GuyWonder_ok.jpg     </content>
        </element>
        <element name="E3" signature="L1V0M4K0">
            <content type="sound" duration="11" autostart="yes">s6.wav</content>
        </element>
     </bloc>
     <bloc name="part 2" position="center">
        <element name="F1" signature="L2V0M0K0">
            <content type="text"><p/><p/>Seule l'information sélectionnée est examinée. L'attention sélective permet donc
de se focaliser sur un point en se coupant mentalement de l'environnement, sans devoir pour autant s'isoler
physiquement.</content>
        </element>
     </bloc>
     <bloc name="Navigation" include="bloc.xml">
        <links>
            <link key_word="PRECEDENT" url="attention_saga3.xml"/>
            <link key_word="SOMMAIRE" url="cours_saga.xml"/>
            <link key_word="SUIVANT" url="attention_saga5.xml" position="1"/> </links>
     </bloc>
    </Page>
```

```xml
                                                                                    bloc.xml
    <Page>
     <bloc name="Sommaire" group="navig"" position="bottom">
        <element name="G1" signature="L1V0M0K0">
            <content type="text">PRECEDENT</content>
            <content type="text">SOMMAIRE</content>
            <content type="text">SUIVANT</content>
        </element>
        <element name="G2" signature="L0V1M0K0">
            <content type="image" link="PRECEDENT" width="190" high="50">precedent.jpg</content>
            <content type="image" link="SOMMAIRE" width="300" high="50">sommaire.jpg</content>
            <content type="image" link="SUIVANT" width="190" high="50">suivant.jpg</content>
        </element>
     </bloc>
     <exclude>L1V0M0K0$L0V1M0K0</exclude>
    </Page>
```

Figure 7: A sample of XML files

These properties give flexibility to our environment but require a good expertise from the author. To support the generation of the XML files, we have built an authoring tool and we have tried to provide information related to the hyper-document in such a way to help the authors to incrementally edit their documents.

The Authoring Tool

Each time a new technique of adaptation is introduced, it is necessary to provide new tools to help authors in building the hypermedia. Ideally, this should be done in using well-known professional tools as provided by Macromedia, Adobe and Microsoft. However, this is rarely the case because these generic tools are not open enough and because they have their own strategies of use. Most adaptive hypermedia authoring tools focus on semantic segmentation of HTML documents, like SEPHYR and OPHELIA in the ARIADNE project (ARIADNE, 2002).

Our approach is slightly different and consists of supporting the assembly of elementary content. To achieve this goal, we built a specific editor using Java. Because the cognitive signature of the elements is not a common feature, we included several functions to help the author in using our tool.

The author creates a site and builds the pages using an incremental process. She can switch to a hierarchical view or an XML view. For each block, the author can specify all the parameters, including the cognitive signature (Figure 8), and add contents (text, sound, image or video) (Figure 9). Many default parameters are set to allow first time users to build the pages very easily. The author can also use a CSS style sheet (referenced in the *style* attribute of the page) and apply the styles to the elements.
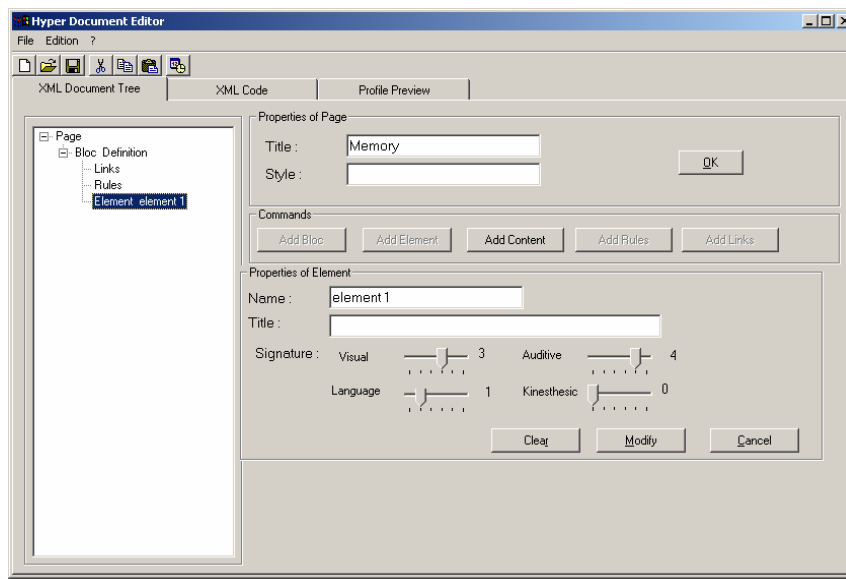

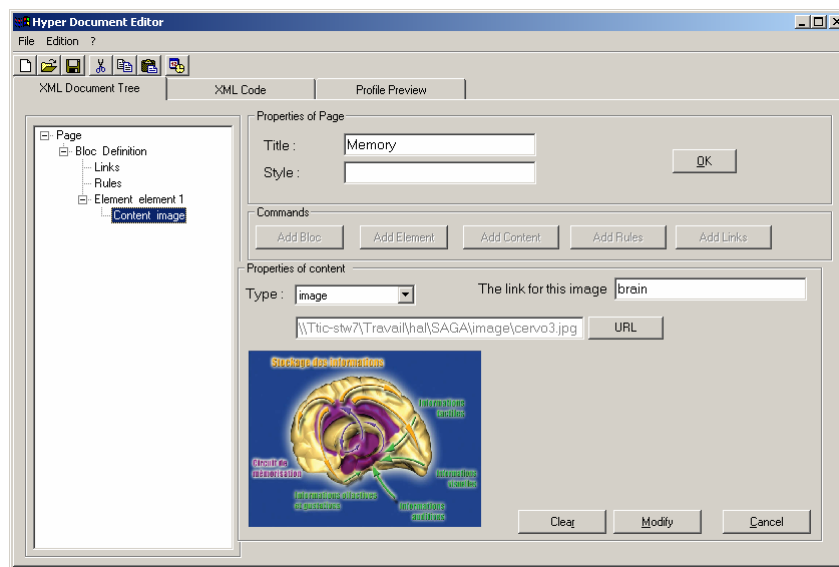*Figure 8:* The hierarchical view of the document and the cognitive signature assignment

Figure 9: Adding contents (image) in an element

To help authors "visualize" what the adapted document will look like, a preview feature has been included in the tool. They just need to quickly build a cognitive profile or select a predefined one (Figure 10) and see the possible results.
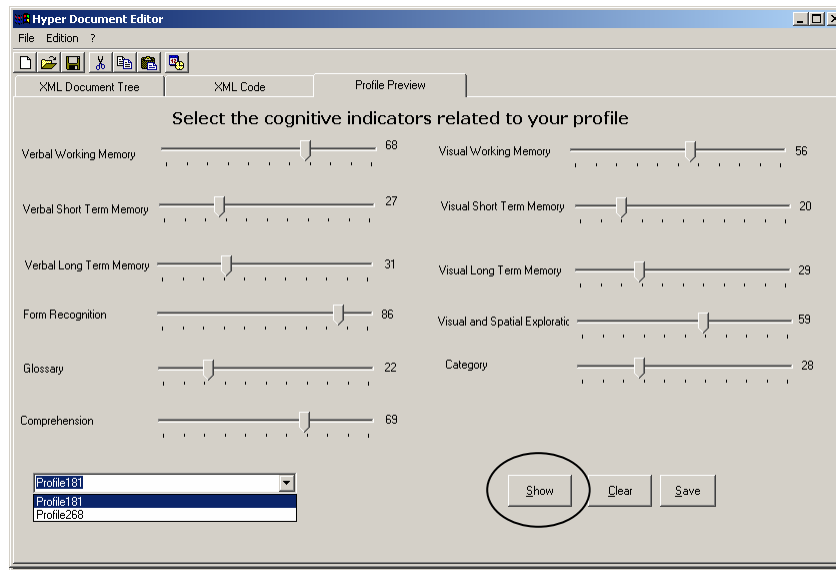

Figure 10: Defining virtual cognitive profile for preview.

3.3. ADAPTING HYPER-DOCUMENTS ON THE FLY

In order to tailor the presentation to each user, dynamic generation of web pages is preferable to storing static pages on disk. Indeed, if the information can be put together in many ways, the sheer number of possible variants can make static pages impractical (Hook, 1997). To build an adapted version of a document, various techniques can be applied, most of which are rule-based (inference rules – Kobsa, 1994, selection rules - De Bra, 2003). In the CUMAPH environment, we use another approach by optimizing numeric criteria.

Principles

To illustrate the adaptation process, we use the sample page presented in Figure 7 and titled *Attention*, which is extracted from a cognitive psychology introductory course called "Brain Saga". Figure 11 depicts its structure.
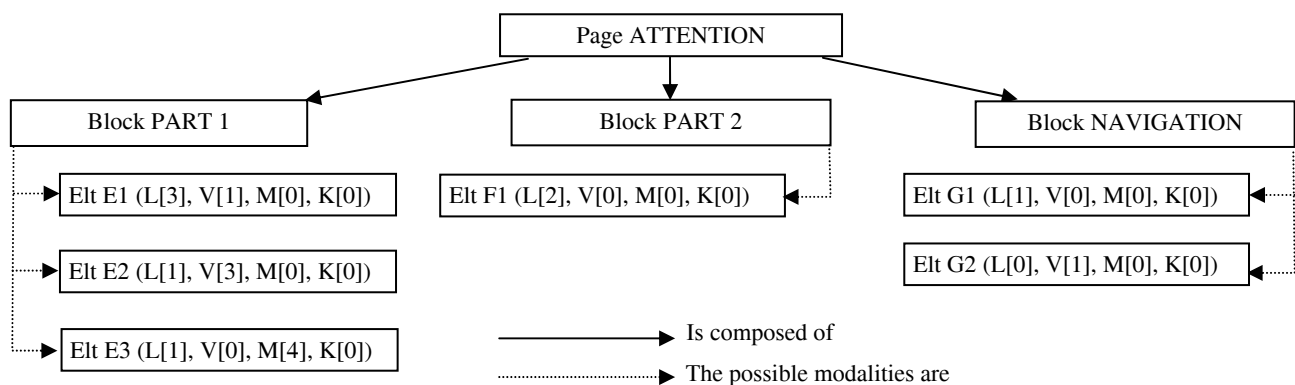

Figure 11: XML document structure

This page has 3 blocks: "PART 1" (3 elements: E1, E2, E3), "PART 2" (one element: F1) and "NAVIGATION" (2 mutually exclusive elements: G1, G2; see the <exclude> tag in the XML file, Figure 7). When a user accesses this page on a web server, the issue is to first find the "best" combination of elements according to the author's goals as well as the reader's abilities, and then to dynamically build and present the selected combination.

Before detailing all the steps of our approach (Figure 12), we sum up its main aspects. First we build a compatibility matrix whose columns correspond to numeric criteria and whose rows are the possible combinations of media types. For each "combination / criterion" pair (e.g. capacity to manage more than one media and respect of preferred media) a compatibility factor is calculated using an arithmetic formula that combines the user cognitive profile and the characteristics of the combination. The combination of media that obtains the highest weighted average of criteria is considered to be the most compatible one. At that stage, we define only two cognitive criteria, but the technique can be extended to cover more, including non cognitive criteria.

Then, the server application (currently a Microsoft ASP program: "engine.asp?file=mydoc.xml") builds in memory an enriched XML document that contains the whole page to be presented ("mydoc.xml") and applies the XSL style sheet on this temporary document. Finally, the resulting HTML file is sent to the Internet browser.
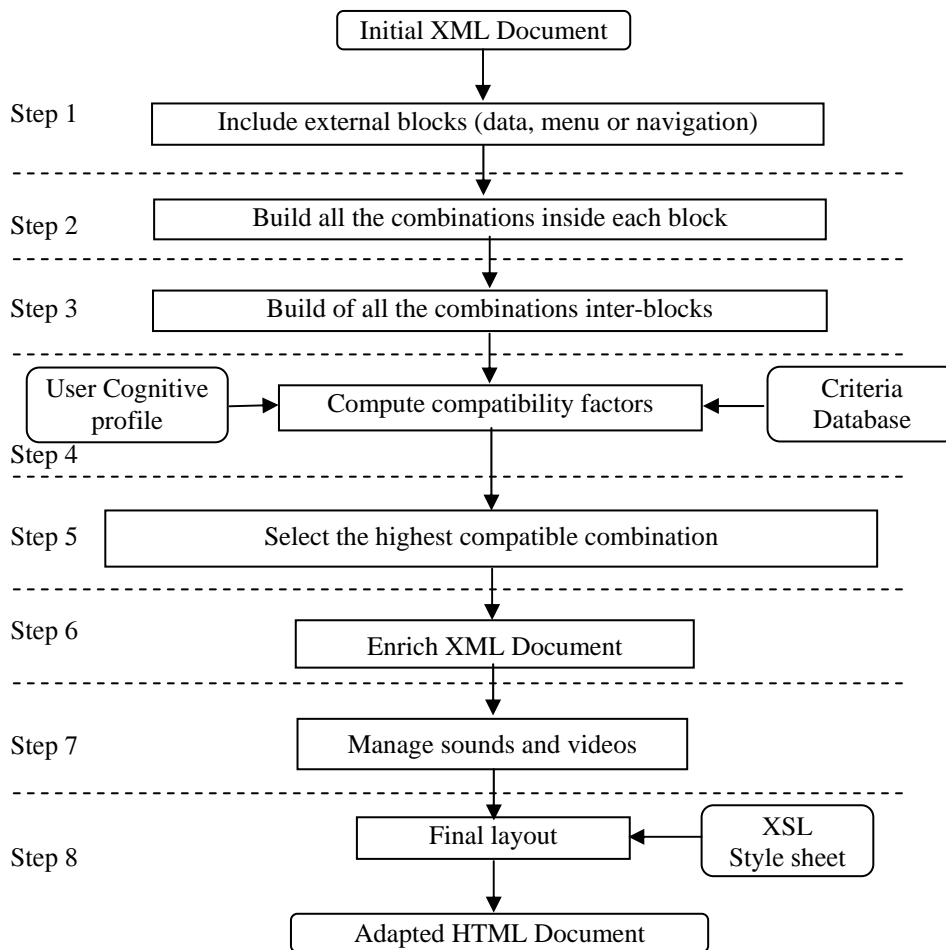
Detailed Process

Figure 12: The algorithm for selecting the "best" multimedia combination

In steps 1 through 3, the process starts by building all the possible combinations respecting the author's constraints (*rules* & *exclude* sections). Because we need global evaluation, the combinations define a full document. In step 4, for each combination, the compatibility factor is calculated by evaluating criteria related to user profile (cognitive indicators) and the document itself (number of media, level of complexity for every media, etc). We can define several criteria but it would be difficult to validate their reliability and efficiency. As a consequence, we have decided to start our experiments only with two criteria. The first criterion (C1) is used to evaluate how much a combination fits to 3 synthetic cognitive indicators respectively called Visual, Verbal and Musical Score. The Visual score is the average of the visual memories and visual-spatial indicators. The Verbal score is the average of verbal memories and language indicators. The Musical score is the average of musical memories. We assume that these scores accurately qualify how much someone will feel comfortable with visual, verbal and musical materials. The second criterion (C2) is used to favor the selection of a multimedia combination. It simply compares the number of modalities of a combination to the highest possible one. **Our goal is to select multimedia combinations that do not overload the cognitive abilities of the user.**

$$(Nb_{Vi}*Sc_{Vi}+Nb_{Ve}*Sc_{Ve}+Nb_M*Sc_M)/(Nb_{Vi}+Nb_{Ve}+Nb_M) \qquad (C1)$$

$$100*(Nb'_{Vi}+Nb'_{Ve}+Nb'_M)/Nb'_{Max} \qquad (C2)$$

with

$$Sc_{Vi}=(WM_{Vi}+STM_{Vi}+LTM_{Vi}+Rec+Exp)/5$$

$$Sc_{Ve}=(WM_{Ve}+STM_{Ve}+LTM_{Ve}+Glos+Cat+Und)/6$$

$$Sc_M=(WTM_M+LTM_M)/2$$

Combination characteristics:
  Nb_{Ve}/ Nb_{Vi}/ Nb_M : Sum of Verbal / Visual / Musical signatures
  $Nb = Nb_{Vi}+Nb_{Ve}+Nb_M$
  $Nb'_{Ve} = Min(1; Nb_{Ve})$ $Nb'_{Vi} = Min(1; Nb_{Vi})$ $Nb'_M = Min(1; Nb_M)$
  Nb'_{Max} : $Max(Nb'_{Vi}+Nb'_{Ve}+Nb'_M)$ for all the combinations
  Sc_{Vi}/ Sc_{Ve}/ Sc_M: Visual / Verbal / Musical scores calculated using cognitive indicators:

Cognitive indicators:
  WM_{Ve}/ WTM_{Vi}/ WTM_M: Verbal/ Visual/ Musical Working Memory
  STM_{Ve}/ STM_{Vi}: Verbal/ Visual Short Term Memory
  LTM_{Ve}/ LTM_{Vi}/ LTM_M : Verbal/ Visual/ Musical Long Term Memory
  Rec: Form Recognition, Exp: Visual and spatial Exploration, Glos: Glossary, Cat: Category, Und: Understanding

Step 4 of the process selects the combination whose **compatibility factor CF** is the greatest one. Currently, we use a weighted mean of the two criteria: CF= (3xC1+C2)/4 (we privilege the cognitive compatibility C1 to the multimedia criterion C2). To show an example of this step which is the heart of the adaptation process, we adapt the sample XML file presented Figure 7, using 3 prototypic cognitive profiles (see Table 2).

Table 2: Cognitive profile for three prototypic users

Indicators Profiles	Sc_{Ve}	Sc_{Vi}	Sc_M	WM_{Ve}	WM_{Vi}	Wm_M	STM_{Ve}	STM_{Vi}	LTM_{Ve}	LTM_{Vi}	LTM_M	Glos	Cat	Und	Rec	Exp
Pr 1 "verbal"	75.0	25.0	50.0	75	25	50	75	25	75	25	50	75	75	75	25	25
Pr 2 "visual"	25.0	75.0	25.0	25	75	25	25	75	25	75	25	25	25	25	75	75
Pr 3 "musical"	25.0	25.0	75.0	25	25	75	25	25	25	25	75	25	25	25	25	25

Considering the page we want to adapt, table 3 lists the possible intra-block combinations with their associated cognitive signature:

Table 3: List of possible intra-block combinations with their associated cognitive signature

Name of the intra-block combination	Block	Element	Ve	Vi	M	K
A1	1	E1	3	1	0	0
A2	1	E2	1	3	0	0
A3	1	E3	1	0	4	0
A12	1	E1+E2	4	4	0	0
A13	1	E1+E3	4	1	4	0
A23	1	E2+E3	2	3	4	0
A123	1	E1+E2+E3	5	4	4	0
B1	2	F1	2	0	0	0
C1	3	G1	1	0	0	0
C2	3	G2	0	1	0	0

The "best" combination for every user is shown (in bold) in the following table. The score values are the weighted average of the criteria given above.

Table 4: Scores related to every combination and the "best" combination for each profile.

inter-block combination	signatures					Profile 1			Profile 2			Profile 3		
	NB_{Ve}	NB_{Vi}	NB_M	NB	NB'	C1	C2	CF	C1	C2	CF	C1	C2	CF
A1 B1 C1	6	1	0	7	2	67.9	66.7	67.6	32.1	66.7	40.8	25.0	66.7	35.4
A1 B1 C2	5	2	0	7	2	60.7	66.7	62.2	39.3	66.7	46.1	25.0	66.7	35.4
A2 B1 C1	4	3	0	7	2	53.6	66.7	56.8	46.4	66.7	51.5	25.0	66.7	35.4
A2 B1 C2	3	4	0	7	2	46.4	66.7	51.5	53.6	66.7	**56.8**	25.0	66.7	35.4
A3 B1 C1	4	0	4	8	2	62.5	66.7	63.5	25.0	66.7	35.4	50.0	66.7	54.2
A3 B1 C2	3	1	4	8	3	56.3	100.0	67.2	31.3	100.0	48.4	50.0	100.0	**62.5**
A12 B1 C1	7	4	0	11	2	56.8	66.7	59.3	43.2	66.7	49.1	25.0	66.7	35.4
A12 B1 C2	6	5	0	11	2	52.3	66.7	55.9	47.7	66.7	52.5	25.0	66.7	35.4
A13 B1 C1	7	1	4	12	3	62.5	100.0	**71.9**	29.2	100.0	46.9	41.7	100.0	56.3
A13 B1 C2	6	2	4	12	3	58.3	100.0	68.8	33.3	100.0	50.0	41.7	100.0	56.3
A23 B1 C1	5	3	4	12	3	54.2	100.0	65.6	37.5	100.0	53.1	41.7	100.0	56.3
A23 B1 C2	4	4	4	12	3	50.0	100.0	62.5	41.7	100.0	56.3	41.7	100.0	56.3
A123 B1 C1	8	4	4	16	3	56.3	100.0	67.2	37.5	100.0	53.1	37.5	100.0	53.1
A123 B1 C2	7	5	4	16	3	53.1	100.0	64.8	40.6	100.0	55.5	37.5	100.0	53.1

In steps 6 and 7, the process is enriching the XML file to prepare the final layout.

First, the "state" attribute of each element has the value 1 if the element belongs to the selected combination. If not, the engine compares the cognitive signature of the element to one of the selected elements. If it is richer in one or more

dimensions (LVMK) the element can be useful even if it seems unsuitable to the user profile. For example, a definition may be presented to the user in a textual form with small graphical illustration, whereas, the complete information can be presented with a detailed diagram. In this case, the "state" attribute is given the value 2, otherwise it would be 0. Because the user can look for something specific that has not been selected by the automatic process, all elements that have "state=2" will be displayed as small icons on which the user can click to view or hear the element in a popup window.

Finally, the system automatically computes another signature called "material signature" for each element as sign_mat="TaIbSc" with a, b and c ranging from 0 to 5, and adds it to the XML structure. This signature is related to the physical characteristics of the media. a refers to the length (number of characters) of texts (T). b refers to the dimension (width and height) of images and video (I). c is related to the duration of sounds and video (S). This signature is used in the last step to help in choosing between several layout patterns.

In step 7, the engine detects if some sounds have to be automatically played. In this case, the temporal sequences that will be used by javascript codes are changed according to audio files characteristics.

3.4 THE FINAL LAYOUT

The last step of the adaptive process is to apply an XSL stylesheet to visualize the output document (i.e. the document enriched by the adaptive engine). In order to be independent from the browser, this operation is done on the server side. The HTML page that results from this operation is sent to the browser.

Because general human factors and usability rules have to be considered for the layout, we defined rules to build efficient and coherent layouts. These rules can be further improved using more sophisticated layout patterns.

According to the number of blocks and their contents, the screen is divided into partitions (based on the 5 positions described in section 3.2). "Top" and "Down" areas are split horizontally whereas "Left, "Center" and "Top" are split vertically.

Inside each block, the spatial dispositions change according to material signatures:

- If an element contains only one media, 100% of the area width is used.

- If the element contains multimedia information, several cases are considered depending on the material signature (*sign_mat*). For instance, if textual and graphical contents have medium dimensions, they are displayed together. If the graphical content is larger than the textual one, the image is displayed above the text (the text is probably the image caption).

The icons related to the reduced elements are presented on the right, just after the displayed elements (with state "1"). The user can access the alternative elements by clicking on these icons.

The hyperlinks are created by considering the data given in the link tag (i.e. keywords, addresses and positions). If an address belongs to the same document, the stylesheet changes and redirects it to the adaptive engine (e.g.: "/engine.asp?page=mypage.xml"). The "positions" attribute allows to create links only for some occurrences of keywords (i.e. the positions given in the tag link). For example, if we find many occurrences of the keyword inside the text, only the given positions (the first, the last, the first two, etc.) will be tagged.

These treatments end the transformation process, the HTML output document is transmitted to the web browser to be displayed.

Figure 12 presents the results of the adaptation of the sample page according to the 3 cognitive profiles (Table 4).
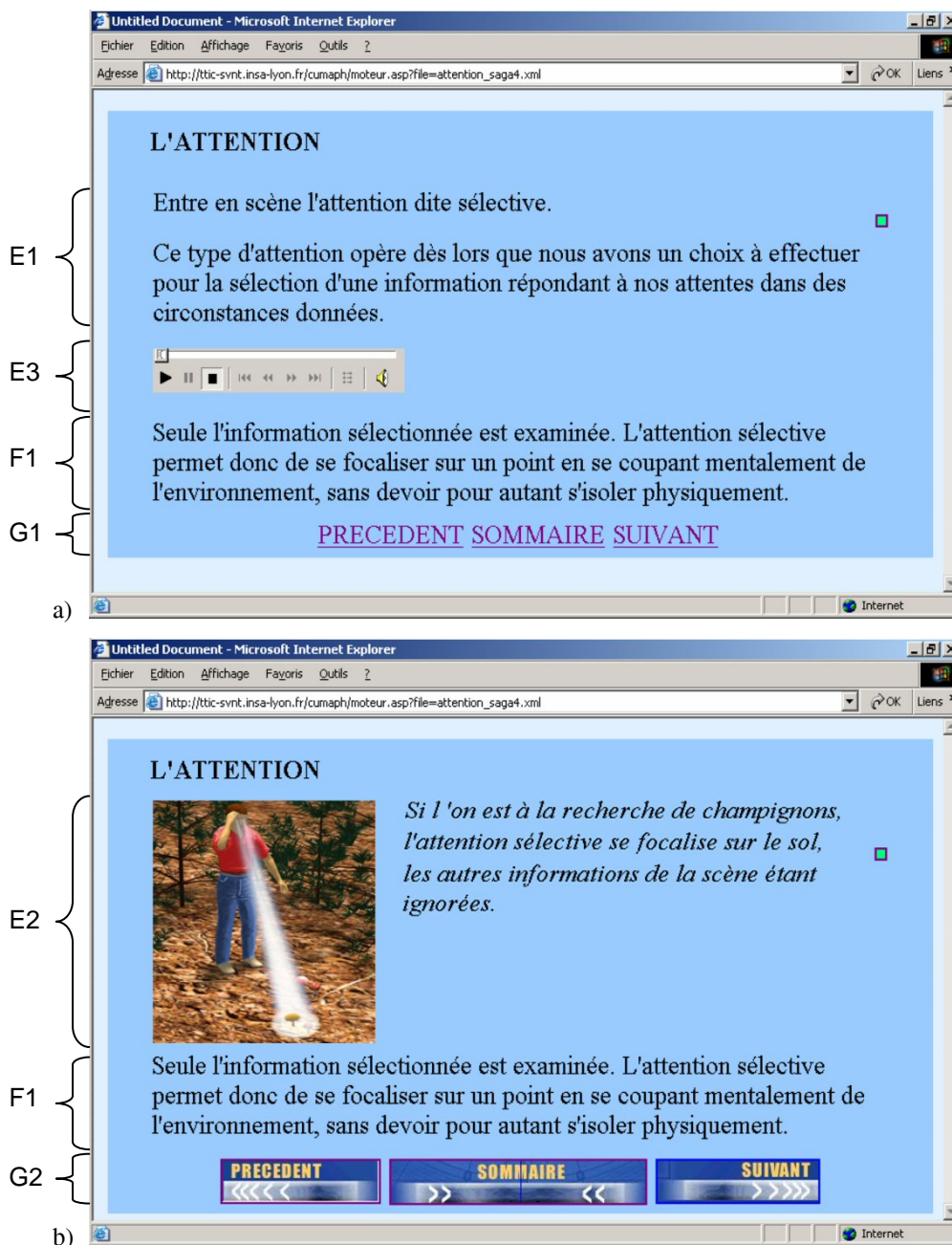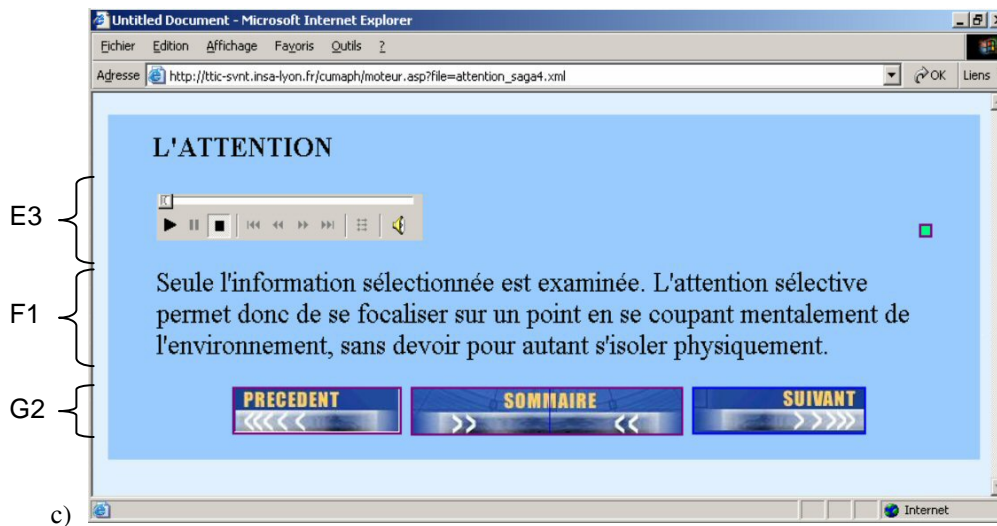
Figure 12: The same page presented to 3 prototypic profiles (a: "verbal", b: "visual", c: "musical")

These three presentations of the same document do a good job in illustrating the results of the adaptation process. Of course, it is difficult to explain why these presentations have been selected as they are resulting from a maximization process. However, we notice that they seem to be very coherent with the profiles: the verbal profile obtains a full-text presentation and an audio verbal comment, the visual profile has a picture instead of a textual explanation, and the musical profile has the audio comment and a visual navigation bar.

4. The Experiment

4.1. THE PROTOCOL

David Chin (2001) stressed the importance of empirical evaluation of adaptive systems. He first underlined, that statistical analysis require large group of subjects, and second, that it is often difficult to build a control situation (e.g., a control group for the system without user modeling). Indeed, the most common approach to evaluating an adaptive system is to compare it to its non adaptive version. This approach was adopted by the evaluations of both MetaDoc (Boyle, 1994) and PUSH (Hook, 1997). Although these evaluations showed that the adaptive versions of the systems improved users' performance in several information tasks, the quality of the non-adapted version can often be argued. Other approaches consist of splitting a population into two opposite groups A & B (e.g. visual vs. verbal profile) and experiment the system using counter balanced situations. This technique is very efficient if it is possible to split the population into opposite groups. In our situation, this technique is not applicable because cognitive profiles are supposed to be very heterogeneous.

In order to prove that our adaptation system has positive effects, we applied an innovative protocol. Our experimental hypothesis is as follows: if we are able to show that an adaptation based on a cognitive profile that is close to the user cognitive profile has better results than an adaptation based on a cognitive profile that is far from the user cognitive

profile, it means that the benefits are attained by the adaptation process and not by the quality of the media used. So, we used the following method:

- Each subject performs a module (the 6 interactive exercises presented in section 3.1) that builds up his/her real cognitive profile;

- For each subject, we generate a randomized cognitive profile (a set a random indicators ranging between 10 and 90);

- We give them 20 minutes each to navigate through a web-course that is adapted according to the randomized profile. For the purpose of the experiment, the function that reduces the non selected elements (state=2) into icon has been disabled in order to present only the elements chosen by the system;

- We evaluate their new knowledge using a questionnaire with open questions, which gives a mark between 0 and 100 (later called Mark). A qualitative final question is asked "Give a value range from 1 to 5 to qualify the overall quality of presentation of this course". This value is later called "Feeling".

Then, we analyze the results and try to show that coherent adaptation, i.e. when the randomized profile is close to the real profile, give better results than less coherent adaptation, i.e. when then randomized profile really differs, regardless of the real profile. The validity of our approach can potentially be affected by two risks: (1) the random creation of profiles might result in implausible and unnatural profiles (e.g., combinations that cannot occur in real life or extreme values that cannot practically occur), (2) the global distribution of the randomized profiles is not fully homogenous (either because the number of subjects was insufficient or we were unlucky with the random algorithm). In our case, there is not a big risk for the first phenomenon as (1) we keep values within range [10, 90], which is not above 1.28 standard deviation, and (2) we only use three synthetic values (Sc_{Vi}/ Sc_{Ve}/ Sc_M), which can have no correlation. Of course, if we plan to introduce other criteria, we should check this point carefully. For the second risk, we graphically verified that the random values seem to be homogeneous. However, for deep analysis, this should be insufficient. We suggest carefully validating the distribution of the random profiles for similar experiments.

42 subjects (third year students in industrial engineering at INSA-LYON participated in the experiment. After the evaluation module, 3 subjects were excluded because they had inadequate mastering of the French language leading them to misunderstand tasks in the test module and thus to have aberrant profiles. They were initially included because we were hoping to see effects of non-native speakers. Consequently, 39 students have been included in the analysis: 15 women and 24 men, between 19 and 22 years old.

For the second step of the experiment we used a hyper-document called "*Saga du Cerveau*" (Brain Story), which explains what cognitive abilities are (Habieb_Mammar et al., 2003). This course has been generated with our authoring tool and contains 21 pages. Its contents were chosen because the initial knowledge of each subject was almost null on

the topic and in all cases insufficient to correctly answer the questionnaire. Indeed, the subjects belong to an engineering school and have not taken courses in cognitive psychology. The questions in the evaluation questionnaire were difficult enough to ensure that good answers come from recent knowledge and not from previous knowledge.

Before presenting the results of our experiment, we introduce the set of variables we used.

Considering the criteria we are currently using in the compatibility matrix and to simplify the analysis, we summarized the 13 cognitive indicators given by the evaluation module in 3 scores: verbal (Sc_{Ve}), visual (Sc_{Vi}) and musical (Sc_M) (see section 3.3 for more details). We also defined a general Profile score as the mean value of the 13 cognitive indicators. As all the indicators are normalized (see section 2.3) we consider this operation as legal. This very synthetic score characterizes attentional and memorization abilities. Our assumption is that people with high value should have better memorization and understanding performances than people with low value, and so, should have better results in our final questionnaire.

In order to estimate the coherence between the real profile (Sc_{Ve}, Sc_{Vi}, Sc_M) and the randomized profile (RSc_{Ve}, RSc_{Vi}, RSc_M) we need to define an "adaptation distance". Currently we chose to use the Euclidian distance between both profiles:

$$Distance = \sqrt{\left(Sc_{Ve} - RSc_{Ve}\right)^2 + \left(Sc_{Vi} - RSc_{Vi}\right)^2 + \left(Sc_M - SSc_M\right)^2}$$

To segment population, we also decided to split Profile and Mark into 6 classes based on the mean value (M) and the standard deviation (S): [<M-2S] [M-2S ; M-S] [M-S ; M] [M; M+S] [M+S ; M+2S] [>M+2S]. That way, for each subject according to the class they belong to, we defined 2 values, cProfile and cMark, which range from 1 to 6.

Finally, we need to study a value called "evolution" (E) which is the difference between cMark and cProfile. This value shows the ranking evolution of a subject considering his cognitive potential (cProfile) and his exam result (cMark). Indeed, if E is positive, this means the subject has a better position in the evaluation test than his cognitive profile suggests. On the other hand, a negative value shows a regression. This value is very interesting because it does not depend on the user level but shows whether the adaptation process helps obtain better results.

4.2. RESULTS AND DISCUSSION

We divide this section in two parts: description of the subjects' profiles and analysis of the adaptation effects.

Subjects' profiles

We first want to characterize the profiles distribution in our experimental population to check (1) if we have any biases (abnormal distribution) and (2) if it was possible to cluster the population, which would have encouraged using other validation protocols. Four results seem interesting to comment on (Table 5).

Table 5: Subjects' profiles characterization.

Result	Definition	Values
R1	Profile distribution	Mean M = 51.2, Standard deviation S =10.5 We split the population into six classes: [<M-2S] [M-2S ; M-S] [M-S ; M] [M; M+S] [M+S ; M+2S] [>M+2S]. Each subject belongs to one of these classes, which is associated with a code called cProfile (range 1 to 6). See Figure 13.
R2	Correlation between visual and verbal scores	Pearson correlation 0.70 with p=0.0005
R3	No correlation between musical and verbal scores	Pearson correlation 0.18 with p=0.25
R4	Visual Score vs. Musical Score distribution	The distribution of the profiles is large and no clusters emerge (Figure 14).
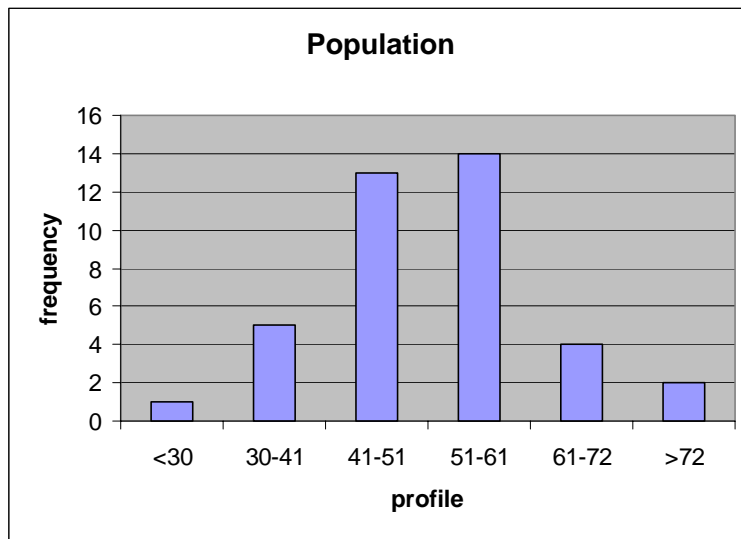
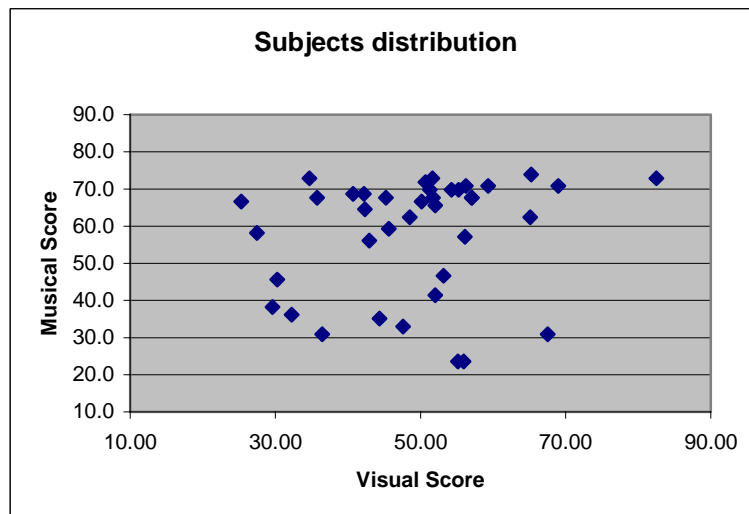*Figure 13:* The profiles of the subjects (average of the thirteen cognitive indicators).

Figure 14: Visual vs. Musical Scores.

R1 shows that our experimental population is well distributed (close to a Gaussian distribution). We detect a strong correlation between visual and verbal scores (R2). This is not a big surprise because reading verbal materials requires visual abilities. Reciprocally, while trying to memorize images, users can apply verbalization strategies. Both phenomena appear during the evaluation process. This is not the case for the musical score as no verbalization

strategies are effective (R3). For future experiments, we will probably adjust the evaluation module by introducing one additional exercise with visual material that can not be verbalized.

R4 shows that the distribution of subjects in terms of Visual Score vs. Musical Score is dispersed. We are not able to have a clear clustering of the population. This confirms one of our hypotheses. Indeed, the difficulty to define clusters and hence classes of subjects underlines (1) the limits of adaptation techniques based on stereotypes and (2) the complexity of defining validation protocols with control situations.

Adaptation Effects

Now, we verify if we can observe positive effects of the adaptation (Table 6). Our first concern is to analyze the relationships between the distance of adaptation and other values such as Mark and Evolution. In order to do ANOVA analysis, we want to split the population into two groups according to the distance value.

Table 6: Adaptation effects characterization.

Result	Definition	Values
R5	Distance distribution	Distance value ranges from 11.8 to 86.1 Mean M = 44.2 and standard deviation S = 17.7 We split the population into 2 classes according to the Distance value: short distance (D<44.2) and long distance (D>44.2). 19 subjects belong to the first group (cDistance=1) and 20 belong to the second (cDistance=2).
R6	Mark vs. other values	Correlation Mark/cDistance : -0.45 with P-value=0.0033 ANOVA analysis for Mark by cDistance: F-Ratio=9.89, P-Value=0.0033 Correlation Mark/Distance (see Table 7) ANOVA analysis for Mark by cProfile: F-Ratio=0.61, P-Value=0.70 Correlation Mark/Profile: 0.12 with P-value=0.46
R7	Correlation Distance/Evolution	Correlation Distance/Evolution = -0.40 with p=0.012 ANOVA analysis for Evolution by cDistance: F-ratio=9.64, P-value=0.036
R8	No correlation with Random Profile	Correlation Mark/Random Profile = -0.06 with P-value=0.70 Correlation Evolution/Random Profile = 0.08 with P-value=0.61
R9	No significant correlation with gender	ANOVA analysis for Mark by gender F-Ratio=0.60, P-Value=0.4445 ANOVA analysis for Evolution by Gender: F-Ratio=0.87, P-Value=0.3569
R10	Correlation Feeling/cDistance	ANOVA analysis for Feeling by cDistance: F-Ratio=5.26, P-Value=0.0276

Table 7: Correlation Mark / Distance considering sub-populations

Population	Full	Without the 4 highest profiles	The 23 lower profiles	The 15 lower profiles
Number of subjects	39	35	23	15
Correlation Mark / Distance	-0.18	-0.31	-0.40	-0.54
P-Value	0.27	0.06	0.05	0.03

Because of the randomization process, the Distance has a large range (R5). However, because of the Distance formula, the distribution is naturally higher for medium Distance. For future experimentation, we suggest to apply more sophisticated algorithms to determine the random profile in order to have a more constant distribution of the Distance value. In the mean time, we have defined two numerically equivalent populations on both sides of the mean value (called short and long distance; cDistance=1 or 2).

R6 shows that since the P-value of the F-test is less than 0.01, there is a statistically significant difference between the mean Mark from one level of cDistance to another at the 99.0% confidence level (see Figure 15). This is a very positive result. Surprisingly, when we calculate the correlation between Distance and Mark (the raw data) we find no significant correlation for the full population. Nonetheless, a significant correlation can be observed if we focus our attention on lower profiles (Table 7). These results suggest that stronger effects can be observed with people who have lower profiles. Finally, this is not unexpected, looking at the fact that high level profiles adapt better to unadapted media thus obtain acceptable marks. To check if no direct effects can be driven by the cognitive level of the subjects, we have computed both ANOVA analysis for Mark by cProfile and correlation Mark / Profile, which show that there is no statistically significant difference between the mean Mark from one level of cProfile to another.
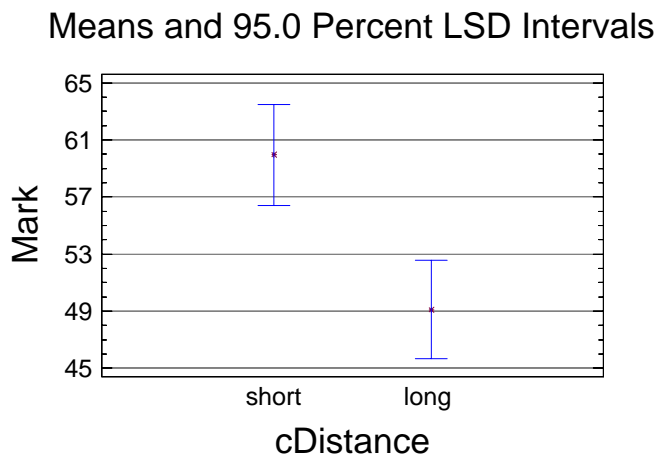

Figure 15: Mark according to the adaptation distance.

In order to neutralize the real cognitive level of the subjects, we have analyzed the correlation between the Evolution value and the Distance. R7 clearly shows that the evolution is statistically higher when the distance is short than when it is long (Figure 16).

In order to verify that no other factors can explain the results of the experiment, we analyzed the relationships between Mark and Evolution on one side and Random Profile and Gender on the other. R8 shows that there are no correlations between the Random profile and both Mark and Evolution. This confirms that the performance does not depend on the random profile, which is -of course- very important! R9 shows the same results concerning the gender variable.
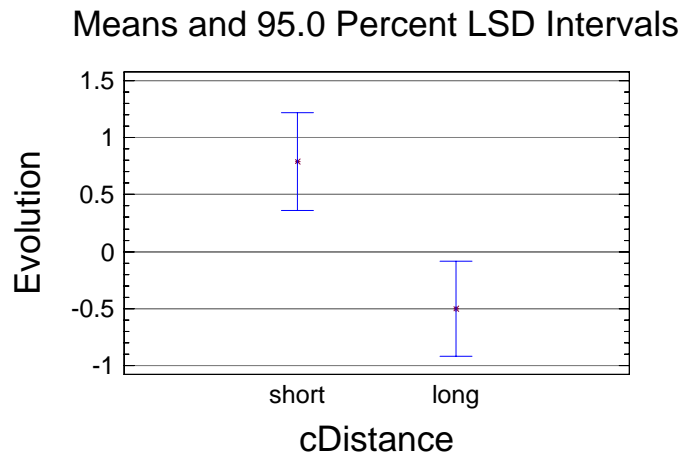
Means and 95.0 Percent LSD Intervals

Figure 16: Evolution according to the adaptation distance.

The final result (R10) concerns the subjective opinion on the course. There is a significant difference at the 97% level of confidence in favor of the short distance adaptation concerning the quality feeling (Figure 17). This is a very interesting result because it shows that, in addition to performance effects, a subjective positive effect can be observed.
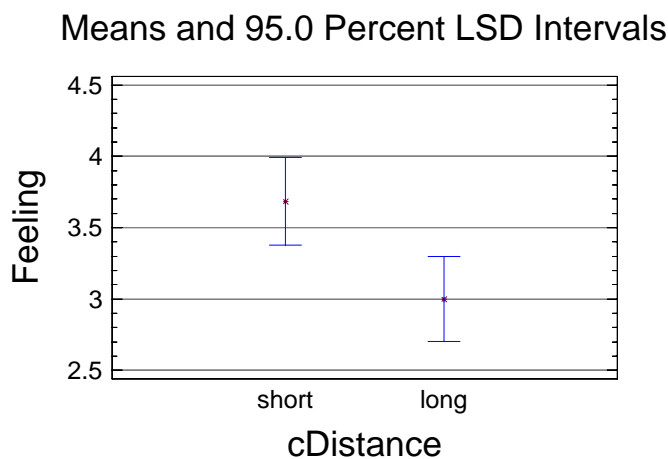
Means and 95.0 Percent LSD Intervals

Figure 17: Feeling (user's subjective appreciation of the course) according to the adaptation distance.

5. Conclusion

In this paper we presented a new way to model cognitive abilities, thus defining the concept of the elementary cognitive indicator. We implemented CUMAPH, an environment for adaptive hyper-document presentation based on four components: a cognitive user model, a hyper-document generator, an adaptive engine and a generic style sheet to present the adapted hyper-document. The adaptation process is mainly based on the maximization of a set of numeric criteria that involve the cognitive indicators and the cognitive signatures of the elements of the document. We currently use simple linear criteria that can probably be extended and optimized. In addition, our architecture can be re-used for other adaptation contexts like cultural or even emotional adaptation if it is possible to build such indicators.

To validate our approach we defined an innovative protocol, which consists of proposing adaptation based on randomized profile and analyzing performances according to the distance between the real and the randomized profile. The results of our experiment clearly show that adaptive presentation of hyper-documents can contribute to the improvement of the performance of users in memorizing and understanding hyper-documents. The interest of our approach is to decrease the cognitive load as we only present necessary items. Patterns of layout allow considering some human factors and ensure that the adapted document will respect usability rules. In our consequent work, we began to introduce extra features like the ability to change the navigation patterns when we are in presence of a long list of items. We offer one page, which requires visual exploration but no memorization, vs. one index page and many satellites pages, which require memorization abilities but no visual exploration. This simple example illustrates that many other applications can probably be found for the cognitive indicators approach.

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